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Analysis of an anaesthetic gas scavenging system hazard

The collapse of the reservoir bag in a circle circuit was observed during anaesthesia. This resulted from the incomplete closure of the pressure relief valve on the absorber while it was connected to the scavenging system. Although the scavenging system was operating and installed according to the manufacturer's recommendations and to the CSA standard on Anaesthetic Gas Scavenging Systems (Z168.8), the patient was not protected from this hazard. Introducing an air break into the scavenging interface device will protect the patient. However, such a system would not meet the CSA standard and would make the relief valves on the scavenging interface device unnecessary.

Scavenging of waste anaesthetic gases has become widespread in the operating room, and a number of hazards has been described. These include airway obstruction and misconnection,^{1,2} excessive negative pressure in the patient breathing system,³⁻⁵ and collapse of the reservoir bag in the patient circuit.⁶ We wish to report our experience with a hospital gas scavenging system which caused a hazard by the evacuation of anaesthetic gases from the patient circuit.

Case report

A 60 kg male, whose trachea had been intubated, was breathing two per cent halothane in nitrous oxide and oxygen (4:2 L·min⁻¹) spontaneously through a circle system. The pressure relief valve (PRV) was connected to a Penlon Papworth Safety Block MKII®* in conjunction with the hospital scavenging system. The fresh gas flow to the circle system was reduced to 3 L·min⁻¹ and shortly thereafter the 2 L circle system reservoir bag was noted to

be collapsed. The PRV was partly closed and the patient circuit filled with oxygen from the emergency source. Nitrous oxide and oxygen (4:2 L·min⁻¹) was then delivered and the resistance in the PRV increased by closing the valve half a turn clockwise (closed) and the anaesthetic was completed without any further problem. There was no injury to the patient.

Equipment

The equipment involved in this incident includes a Penlon Jumbo Absorber (catalogue #52571) with a pressure relief valve (PRV) also known as an adjustable pressure limiting valve (APL valve) connected to a Penlon Papworth scavenging interface Block MKII (Catalogue #52473) by corrugated plastic tubing. Similiar tubing delivers the scavenged gases to the built-in gas disposal system in the ceiling of the operating room. The gas disposal system is composed of an exhaust fan and ducts specifically designed to evacuate sufficient volumes of gas at very low pressures. A variable air gap in the ceiling of the operating room can be adjusted to ensure removal of adequate volumes of gas at very low negative pressures. A schematic diagram is shown in the Figure.

Theory of operation

A scavenging system reduces exposure of operating room personnel to waste anaesthetic gases. In order for gas to flow through the system there must be a pressure differential along the tubing. Passive systems have a conduit to the atmosphere outside the operating room and the pressure is raised above atmospheric by the patient exhaling, the anaesthetist manually squeezing the reservoir bag, or a ventilator. When the distance to the outside is excessive, a fan or venturi device is incorporated in the duct to generate a pressure differential to achieve the desired flow rate. Other active systems that use the hospital suction supply may generate a much greater negative pressure to the patient than a low pressure system and have the potential to cause barotrauma should the system malfunction.^{7,8}

The scavenging interface block protects the patient from excessive positive or negative pressures when an active scavenging system is in use. The scavenging interface block is simply a section of tubing with a

Key words

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FIGURE Patient circuit and scavenging system.

reservoir bag and high and low pressure relief valve attached to its sides. One end of the scavenging block is attached to the hospital scavenging system while the other is connected to the exhaust from the patient circuit (Figure). The reservoir bag allows short-term storage of expelled gas when the flow rate exceeds the average capacity of the scavenging system, without causing the positive pressure relief valve to open and pollute the operating room. The positive pressure relief valve prevents the patient from being exposed to excessive positive pressure should there be a downstream occlusion of the hose connected to the hospital scavenging system. The negative pressure relief valve prevents patient exposure to excessive negative pressure should there be a malfunction of the hospital scavenging system. If there is no gas flow from the patient circuit, the pressure inside the scavenging block is the same as the pressure in the scavenging system and the pressure relief valves remain closed. The valves are designed to activate at pressures insufficient to cause pulmonary injury.

The circle breathing circuit admits gas through the fresh gas inlet and exhausts gas through the PRV on the carbon dioxide absorber. The PRV operates by opening when-

ever there is sufficient excess gas within the breathing circuit to increase the pressure difference across the PRV above a certain threshold. This pressure is variable from approximately 100–6,000 Pa (1–60 cm H₂O).

Results of equipment tests

It was possible to duplicate the clinically observed situation as follows. A flow rate of 5 L·min⁻¹ was delivered to the circle system when the patient Y-piece was occluded and the PRV was open. When the fresh gas flow was reduced, to approximately 2 L·min⁻¹, the patient reservoir bag would begin to deflate. With flows of 0.2–0.5 L·min⁻¹ deflation occurred more rapidly. Removal of the hose connecting the PRV to the scavenging interface block promptly relieved the problem.

The individual components of the system were tested and found to be operating correctly. Tests of the complete system when the components are joined together are of interest. When the flow rate to the absorber was reduced as previously described to 0.2 L·min⁻¹, a negative pressure was measured in the absorber. The absolute value of this pressure would gradually decrease as the flow rate was increased to approximately 2 L·min⁻¹ until

a zero or positive pressure was measured in the absorber. Measurements were then taken with the reservoir bag removed and the bag port occluded. The pressure in the scavenging line was -20 to -25 Pa (-0.2 to 0.25 cmH₂O). The pressure drop across the PRV could not be measured, but was less than 5 Pa (0.05 cm H₂O). When tested separately the PRV could not be made to open at pressures less than 70 Pa (0.7 cm H₂O).

Discussion

Scavenging interface blocks were designed to prevent the patient breathing circuit being exposed to a negative or positive pressure sufficient to damage the lungs. They were not designed with enough foresight to protect against the evacuation of the patient circuit through a leak in the pressure relief valve of the patient circuit, or other problems caused by the flow of the gas.

Ideally a PRV should open completely at the specified threshold pressure, offer no resistance to flow while open, and close completely when the pressure difference across the valve drops below the threshold pressure. If the valve opens to the atmosphere the pressure across the valve is the difference between the breathing circuit pressure and atmospheric pressure. If the PRV is connected to a scavenging system the pressure difference is between the negative pressure of the scavenging system and the breathing circuit. This means the PRV opens at a lower absolute pressure. Furthermore, if the valve were not present or if the valve leaks for any reason, the interior of the patient breathing circuit would tend toward this negative pressure. Consequently, as the exterior of the circuit is exposed to atmospheric pressure the circle reservoir bag, the only flexible part of the system, will collapse. Since the flowrate of gas demanded by inspiration is typically several times the flow rate of fresh gas into the circle circuit, collapse of the breathing bag causes a situation in which the patient cannot inspire sufficient gas, but can still exhale easily. This could cause hypoxia. The inspiratory effort of the patient could produce negative pressures in the airway sufficient to cause air embolism, atelectasis or pulmonary oedema.

The manufacturers' data sheet on anaesthetic gas scavenging systems states that "A negative pressure from the disposal system could open the expiratory valve during inspiring and prevent the patient receiving gases from the breathing system. To avoid this, a maximum negative pressure of 50 Pa (0.5 cm H₂O) below atmospheric pressure is specified. The Papworth Block now includes a negative pressure safety valve, which is available for fitting to old systems."⁹ When discussing active systems using specially installed powered ducting they state: "The fan or air mover should be selected from designs capable of producing only very limited negative

pressure. This reduces the need for installation and adjustment of air breaks to reduce suction to safe levels."¹⁰ The Canadian Standards Association standard on Anesthetic Gas Scavenging Systems (Z168.8) states "A scavenging system shall not create a subatmospheric pressure of more than 50 Pa (0.5 cm H₂O) within a gas collecting device."¹¹ The scavenging system in our hospital exhibited a pressure of less than half of these recommended values. The scavenging interface block was installed as recommended by the manufacturer and the hospital scavenging system complies with current CSA standards.

It has been recommended by Dorsch and Dorsch¹² that the rate of flow into the gas disposal system should be adjusted to an optimal level by observing the reservoir bag and the positive and negative relief valves. If the bag is continually collapsed, or the negative pressure relief valve opens frequently, the flow into the gas disposal system should be decreased. If the bag overdistends or the positive pressure relief valve opens frequently, the flow should be increased.¹² This advice was directed to scavenging systems which employ the hospital's central vacuum system. (In a low pressure gas disposal system, the negative pressure relief valve should never open, since the magnitude of the pressure of the system should always be less than the relief valve's activation pressure.) The main rationale for this advice appears to have been in the interests of economy, rather than safety, to reduce the demands made on the central vacuum system.

The scavenging blocks used with vacuum systems usually have an adjustable valve which is used to restrict the flow into the system. Scavenging blocks used with low pressure gas disposal systems do not have any integral method for adjusting the flow. The effect of the above recommendation is to cause, on average, a slightly positive pressure in the scavenging block. In other words, the action of the system is changed from a completely active system to a system which must push the gases into the scavenging system in a manner similar to passive systems. This actively assisted system would provide greater protection from the collapse of the breathing bag in the event of a PRV leak.

In practice, the system is optimal at only one specific flow rate, while the flow rates of the gases to be scavenged are continuously varying. The implications are that the reservoir bag would collapse at flow rates less than the optimal (with the potential for the hazard described in this paper) and may distend to the point of causing the positive pressure relief valve to open at rates above the optimal (causing pollution of the operating room). In a system which is called upon to scavenge from paediatric circuits, adult circuits or ventilators, it is necessary to scavenge at a wide range of flow rates for different procedures

and during a single procedure. With the central vacuum scavenging blocks it would be possible for the anaesthetist to adjust the scavenging valve continually, but this is just one more thing to forget or perform improperly. With a low pressure gas disposal system, such minute-to-minute adjustments are not possible with the current scavenging blocks. The flow is adjusted by the central fan's flow rate and dampers within the gas disposal system. If an attempt were made to reduce the central gas disposal system's flow rate to an "optimal" value, the CSA standard's recommendation of an exhaust capability of 15 to 25 L · min⁻¹ plus any contribution by a ventilator¹¹ could be violated.

Including an air break in the scavenging system partially solves the problems. In the system we describe, an air break is present at the ceiling as part of the gas disposal system but the problem still occurred. A small air break reduces the amount of anaesthetic gas the scavenging system can withdraw, and reduces, but does not eliminate the magnitude of the negative pressure of the scavenging block, thereby slowing the process by which the reservoir bag collapses. Only where there is a complete air break, that is, where the gases are spilled into the operating room at atmospheric pressure and scavenged at a nearby location, would the problem of a collapsing bag be completely solved. However, the effectiveness of the scavenging would be greatly reduced and much higher volumes of gas would have to be removed in order to evacuate the waste anaesthetic gases. Also, a scavenging interface system with an air break would be unable to pass the CSA requirement that the scavenging system leak at less than 0.1 L · min⁻¹ when pressurized to 500 Pa (0.5 cm H₂O) when blocked at the gas disposal system inlet.¹³ If the suggestion of an air break were implemented, there would be no need for the scavenging interface block with its positive and negative pressure relief valves as it is currently designed. This would change the scavenging interface device to an open system, whereas the current standards recommend closed systems.

The immediate problem lies with the pressure relief valve. It does not seat reliably when adjusted to its lowest setting. It is possible that the problem could be solved simply by using a softer seating material, such as rubber, instead of the metal to metal seating arrangement currently employed. However, this would not address the issue that a scavenging interface block, fitted with a high and low pressure relief valve and reservoir bag, and operating according to current standards will not protect the patient circuit from a hazard should the PRV leak.

The scavenging interface block is convenient when using more than one anaesthetic circuit. We currently scavenge a paediatric circuit, an adult circle system, and a

ventilator into the block which is mounted on the back of our anaesthetic equipment. Until we can find a permanent solution to the problem of gases being evacuated from the circle system, we have removed the reservoir bag from the scavenging interface block and replaced it with a short length of 15 mm tubing in order to reduce spill-over of anaesthetic gases during periods of peak flow from the scavenged circuit. This solution effectively introduces a large air break (thereby reverting to an open type of scavenging system) which renders the relief valves on the scavenging block unnecessary.

In summary, the current designs and standards for closed scavenging systems do not protect the patient from a collapsed reservoir bag when the PRV leaks. The introduction of a large air break in the scavenging interface device will protect the patient from this hazard, but makes the relief valves on the scavenging interface device unnecessary and violates portions of the CSA standard.

References

- 1 Burns THS. Pollution of operating theatres: is scavenging more dangerous than pollution? *Anaesthesia* 1979; 34: 823.
- 2 Sainsbury DA. Scavenging misconnection. *Anaesth Intensive Care* 1985; 13(2): 215-6.
- 3 Mallory WF, Wightman AE, O'Sullivan D, Goldiner PL. Bilateral pneumothorax from suction applied to a ventilator exhaust valve. *Anesth Analg; Current Researches* 1979; 58: 457-9.
- 4 Sharrock NE, Leith DE. Potential pulmonary barotrauma when venting anesthetic gases to suction. *Anesthesiology* 1977; 46: 152-4.
- 5 Mostafa SM, Sutcliffe, AJ. Antipollution expiratory valves. A potential hazard. *Anaesthesia* 1982; 37: 468-70.
- 6 Hawkins TJ. Anaesthetic gas scavenging systems. *Anaesthesia* 1984; 39: 190.
- 7 Sharrock NE, Leigh DE. Potential pulmonary barotrauma when venting anesthetic gases to suction. *Anesthesiology* 1977; 46: 152-4.
- 8 Seymour A. Possible hazards with an anaesthetic gas scavenging system. *Anaesthesia* 1982; 37: 1218-9.
- 9 Anaesthetic gas scavenging systems (A.G.S.S.) Document No. AGSS/DS/180. August 1980 Data Sheet, Penlon Ltd. Radley Road, Abingdon, OXON OX143PH England, p. 5.
- 10 Anaesthetic gas scavenging systems (A.G.S.S.) Document No. AGSS/DS/180. August 1980 Data Sheet, Penlon Ltd. Radley Road, Abingdon, OXON OX143PH England, p. 15.
- 11 Technical committee on anaesthetic equipment and respiratory technology. CSA Standard CAN3-Z168.8-M82, p. 10.

- 12 Dorsch JA, Dorsch SE. Understanding anesthetic equipment. 2nd Ed. Baltimore/London. 1984; p. 259.
- 13 Technical committee on anaesthetic equipment and respiratory technology. CSA Standard CAN3-2168.8 – M82, p. 9.

Résumé

Un affaissement du ballonnet dans un système circulaire a été observé en clinique. Il fut occasionné par la fermeture incomplète de la valve de surpression sur l'absorbeur de CO₂ en présence d'un système d'antipollution. Même si le système anti-pollution était fonctionnel et installé selon les recommandations du manufacturier et répondait aux normes CSA sur l'évacuation des gaz anesthésiques (Z168.B), le patient n'était pas protégé contre cet accident. La création d'une prise d'air dans le système anti-pollution aurait protégé le patient. Cependant, un tel système ne répondrait pas aux normes de la CSA et rendrait la valve de surpression inutile.